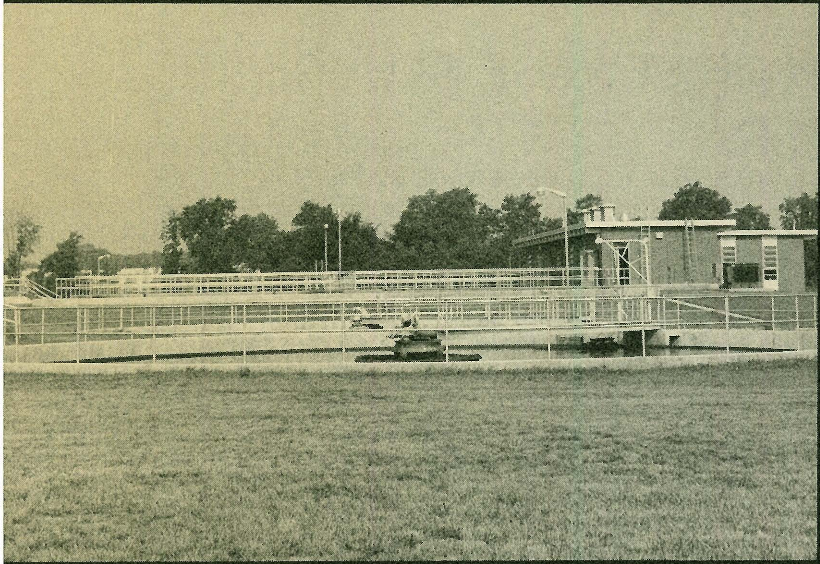
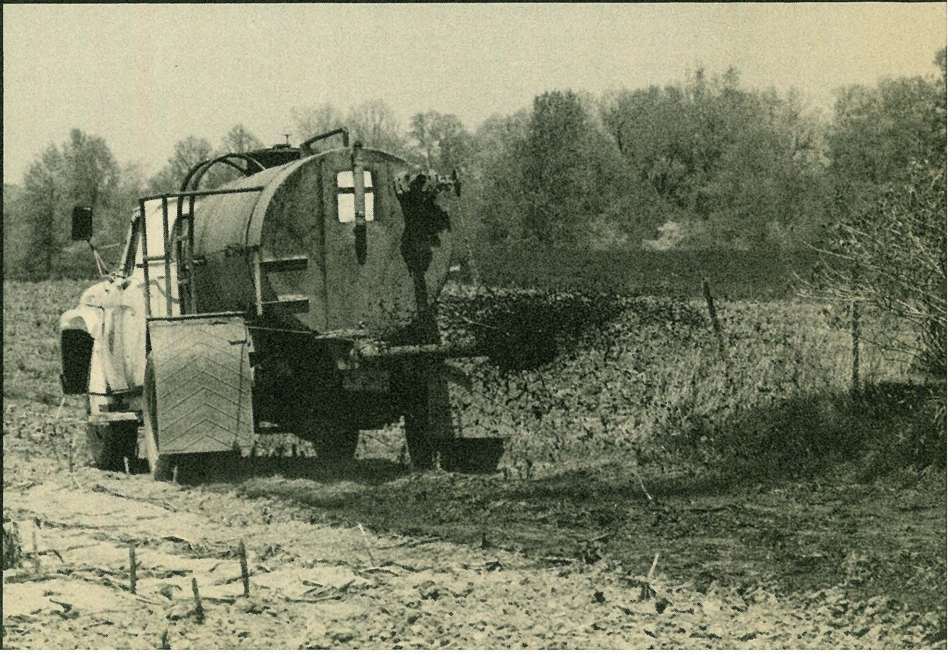
Research Bulletin 1079
Ohio Agricultural Research
and Development Center

Bulletin 598
Cooperative Extension Service
The Ohio State University



Ohio Guide for

Land Application of Sewage Sludge



OHIO GUIDE FOR

LAND APPLICATION OF SEWAGE SLUDGE

REPORT OF THE TASK FORCE ON LAND APPLICATION OF SEWAGE SLUDGE

An increasing number of landowners, local officials and other citizens have been asking questions about the application of sludge to farm land. Sludge has been applied to land for a number of years in some communities. However, recent action by the U.S. Environmental Protection Agency, increased costs of fertilizer, and a concern for efficient energy utilization have generated further interest in the handling of sewage sludge.

On one side of the coin, *municipalities* are faced with the problem of how best to dispose of sewage sludges that are produced by the urban and industrial segments of society. Disposal of sludge by current incineration and landfill operation methods now used by most communities has raised serious environmental concerns.

Landowners, though, are concerned about the feasibility of applying sludge to their land. While interested in the economic benefits sludge may have, they are, at the same time, concerned with questions related to application rates, potential hazards of heavy metals, possible odor problems, and health hazards that might be associated with sludge application.

The following guidelines are based on the most recent research information available, and are subject to change as additional research is completed. It must be clearly understood that the information does not indicate what may or may not be acceptable from a regulatory standpoint. Any regulations governing the application of sludge will be developed by the U.S. Environmental Protection Agency or Ohio Environmental Protection Agency and local health departments.

The basic intent of this publication is to assist landowners in making decisions as they consider application of sludge to their land. Further, the content should help local officials understand the limitations and capabilities of soil as a means of sewage sludge disposal. The publication also provides factual information for the general public concerning the nature of the sludge product and its disposal.

A question frequently asked is, "How many tons of sludge can I apply to my land?" It is impossible to answer that question until two prime factors are known: the composition of the sludge, and the physical and chemical properties of the soil. So, before a recommendation can be made, it's necessary that the results of the sludge and soil analyses be available. Then, through the formulas detailed later in this publication, it will be possible to recommend safe limits of application for given sludge, soil, and cropping situations.

CHARACTERISTICS OF SLUDGE

Sewage sludge characteristics may be categorized into physical, chemical, biological, and "nuisance". The characteristics depend on the type of sewage and the sludge treatment processes. Terminology is related to the type of treatment process.

Terminology

Two broad classes of sludge are: 1) untreated (raw), and 2) treated. **Primary sludge** is raw sludge obtained in the primary stage of the treatment plant by collecting settleable and floating solids. **Activated sludge** is obtained in the secondary stage of the treatment plant by settling flocculated bacteria cells that have been feeding on the soluble and suspended organic material in the sewage. Primary and activated sludges are further treated to obtain a **stabilized sludge** in which the organic matter has been decomposed into a relatively stable material. Anaerobic digestion, a common method of stabilizing sludge, produces **digested sludge**. Sludges may also be stabilized by thermal conditioning (wet oxidation) or lime stabilization. Chemical precipitation, gravity, and air flotation processes are used to **thicken** sludge. Vacuum filters, centrifuges, and filter processes are utilized to **dewater** sludge. Sand drying beds, or dehydrators, may be used to produce a **dried sludge**.

Physical Characteristics

The principal physical characteristic of sludges affecting handling and land application methods is the solids content or the related moisture content. If a sludge has 5 percent solids, it is 95 percent water. Three ranges of solids content that relate to different handling methods are shown in Table 1.

Table I. Sludge Solids Content and Handling Characteristics

Type	Solids Content	Handling Methods
Liquid	1-10%	Gravity flow, pump, tank transport
Semi-Solid ("wet" solids)	8-30%	Conveyor, bucket, truck transport (Water-tight box)
Solid ("dry" solids)	25-80%	Conveyor, auger, truck transport (box)

There is an overlap of solids content for the types noted due to characteristics of particular sludges and handling equipment. Normally a sludge with over 10 percent solids will not flow by gravity through a six inch pipe.

Chemical Characteristics

Organic matter content, fertilizer nutrients, and trace elements are the chemical components of concern. Tables 2 and 3 present their range of concentration in sewage sludge. There is great variability due to the sources of sewage and types of treatment. There are also other trace elements present which are not listed in Table 3.

Biological Characteristics

Various pathogenic microorganisms which may cause diseases such as cholera, typhoid, tetanus, and dysentery may be present in sewage sludge as it is applied to the land. These organisms are associated with fecal waste and some of them will survive conventional sewage treatment processes. Additional treatments which would destroy almost all pathogens are:

1) Storing in lagoons for long periods of time.
2) Pasteurizing at 70°C for 30 minutes.
3) Adding hydrated lime to raise the pH of the sludge to 12.
4) Chlorinating or other chemical treatment.

However, most cities do not employ these processes. Furthermore, no process will kill 100 percent of such disease organisms.

The level of pathogens in digested sludge is low, but care should be taken in handling. It is not practical to disinfect sludge prior to land application because of the organic matter present. Recent studies have shown that when sludge is applied to land, microbes are retained at the soil surface and soon die. Therefore, the presence of some pathogens in the sludge should not limit land application of digested sludge. But sludge should not be applied to land during the year when crops are to be grown for raw consumption.

Contents

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Revised May, 1976

Table 2. Range and Median of N, P and K Contents of Digested Sewage Sludge

Component	Range %	Median* %	Median* lbs/ton
Total Nitrogen	2.0-5.0	3.3	66
Organic Nitrogen	1.6-3.0	2.0	40
P (Phosphorus)	0.5-4.0	2.3	46
P_2O_5 (phosphate)	1.1-9.2	5.3	106
K (Potassium)	0.1-2.0	0.3	6
K_2O (Potash)	0.12-2.40	0.4	7

*The median is that value for which 50% of the observations, when arranged in the order of magnitude, lie on each side.

Table 3. Trace Element Concentrations in Digested Sewage Sludge

Element	Range (ppm*, dry wt.)	Median
Boron	6-1000	50
Cadmium	3-3000	15
Chromium	20-30,000	1000
Cobalt	2-20	10
Copper	50-11,000	1000
Nickel	10-5000	100
Manganese	60-7000	300
Mercury	0.5-10,000	5
Molybdenum	20-30	30
Lead	50-20,000	500
Zinc	100-28,000	2000

*Parts per million
Ref: Unpublished data, North Central Regional Committee 118, report entitled "Utilization and Disposal of Municipal, Industrial, and Agricultural Processing Wastes."

"Nuisance" Considerations

Odors are the primary nuisance involved with land application of digested sludge. It is recommended that only digested or stabilized sludge be applied to land.

Odor nuisance can be minimized by management decisions. Spreading should be at least 250 feet from the nearest residence. If large quantities are spread in a short period of time, the distance may need to be increased. If sludge storage lagoons are located in the area of application, they will need to be at least 1500 feet from residences.

Management

Site Selection

The primary reasons for applying sewage sludge on agricultural land are to use the nutrients contained in sludge for crop production and, at the same time, to minimize the environmental objections of sludge disposal. In order to do this, attention must be given to the landscape and soil characteristics of the application site. Suitability of sludge and rates to use will depend on the heavy metal content of the sludge. In the absence of high concentrations of heavy metals, nitrogen and phosphate contents of sludge can limit the amount that should be applied.

The ideal site is one in which sludge materials can be utilized by crops and which will allow no movement of sludge components from soil as runoff or leachate.

The primary site criteria to be considered are landscape features, along with chemical and physical properties of the soil:

Landscape Features:

Slope: Sludge should not be spread on slopes greater than 12 percent. On 6-12 percent slopes, spread only when at least 80 percent of the soil is covered with vegetation, when immediate incorporation is possible, or when erosion control meets recommendations in Ohio Erosion Control and Sediment Pollution Abatement Guide, Cooperative Extension Service Bulletin 594.

Proximity to Water: Sludge should not be spread within 300 feet of ponds, lakes, or drainage ditches.

Flood Hazard: Sludge should not be applied to soils which are subjected to periodic flooding greater than 10 percent chance per year.

Shallow Soils: Sludge should not be applied to soils less than five feet thick overlying fractured bedrock or permeable sands or gravels because of the potential leaching of soluble components of sludge into groundwater.

Water Table: Sludge should not be applied when a perched water table is within a foot of the surface. Soils with high permanent water tables should be avoided or a drainage system should be installed.

Seepage: High rates of sludge application should be avoided on land with pronounced lateral seepage.

Soil Properties:

Chemical:

pH: The pH of the plow layer (0-8") should be near 6.5. Toxic heavy metals are more available to the plant at low pH's. Soil pH's much higher or lower than 6.5 will reduce the ability of microorganisms in soil to decompose sludge.

Cation Exchange Capacity (CEC): Soils with higher cation exchange capacities have greater ability to hold and immobilize heavy metals. The equation given in the heavy metal section relates sludge loading rates to CEC. Cation exchange capacities of Ohio soils are given in milliequivalents per 100 grams of soil (meg/100 g soil).

Table 4. Range of CEC for Ohio Soils

Soil Textural Groups	CEC meq/100 g soil
coarse	5-15
medium	8-30
fine	25-30
organic soils	greater than 50

Organic Matter (OM): Mineral soils with greater than 5 percent OM content are better suited to application of sludges high in heavy metals because OM increases the CEC of the soil and also immobilizes some heavy metals.

Phosphorus Retention: Sludges contain large amounts of phosphorus, all of which will become available with time. High rates of sludge application should not be made on sandy or organic soils because these soils have a low phosphate retention capacity and large sludge applications could result in downward movement of phosphate into groundwater.

Physical:

Texture: Texture is probably the most important physical characteristic of soils because it affects many of the other soil physical properties. In general, the limitations on sludge application by texture include:

Sands, loamy sands: Leaching of nitrates and other soluble sludge components is the major hazard; sands also have low phosphate retention capacity, low CEC and low buffer capacity (does not resist changes in pH).

Loams, sandy loams: These soils have few limitations to sludge application.

Silt loams: Major limitations include soil crusting and erodibility.

Clays, silty clays, clay loams, silty clay loams: Major limitations are poor drainage, poor aeration, and slow permeability.

Structure: Soils with massive subsurface structure restrict water movement, resulting in impaired drainage and poor aeration. The use of sewage sludge on soils with such subsurface horizons (for example, fragipans) should be avoided.

Soil Erodibility: The susceptibility of a soil to erosion depends on many factors, the most important of which are slope, soil texture, and vegetative cover. The greatest hazard is on fine textured soils. Sludge application on sloping (greater than 2 percent), fine-textured soils should be avoided unless vegetative cover is maintained on these soils to increase infiltration.

Unincorporated sludge on bare slopes greater than 6 percent will move during runoff. Erosion control should meet the recommendations in the Ohio Erosion Control and Sediment Pollution Abatement Guide, Cooperative Extension Service Bulletin 594.

Soil Permeability: The rate at which water moves through soil is important in sludge application. Soils with either very high or very low permeability should be avoided. Highly permeable soils are susceptible to leaching, and sludge may contaminate the groundwater. Those with low permeability have internal drainage problems which restrict sludge decomposition.

Drainage: Successful decomposition of sludge in soil requires good aeration and therefore soils with poor internal drainage should be avoided for sludge application. Fine-textured and poorly-drained soils, and soils in depressions should be properly drained before they are used for sludge application.

Most sludges are high in soluble salts, and although this should not be a major problem in high rainfall areas like Ohio, salt accumulation could be a problem in depressional areas.

Summary of Site Restrictions for Sludge Application by Soil Textural Class

Soil Textural Class	Textural Class	Physical	Chemical
Coarse	Sands Loamy sands Sandy loams	Wind erosion, deep leaching	Low P retention, low pH buffer capacity, low CEC
Medium	Loams Silt loams	Dense subsurface horizons including fragipans, crusting	
Fine	Clays Clay loams Silty clay loams	Poor drainage, poor aeration, slow permeability, rapid runoff on sloping areas, erodibility	Salt accumulation

Handling and Application

The principal factor in determining proper application techniques is the physical characteristics of the sludge. Will it be handled as a liquid, semisolid, or solid? It is assumed that the sludge to be applied to land is digested or stabilized. In the digestion process, the total solids content normally ranges from 3 to 5 percent, i.e., 97 to 95 percent water. The solids content can be increased by various processes at the treatment plant, such as thickening, dewatering, or drying. The decision as to equipment for transporting the sludge, applying it to the land, and/or incorporating it into the soil will dictate the solids content that can be used, or vice versa.

Other factors affecting the method of transport and application are: quantity of sludge produced (size of the city), land considerations (topography, vegetative cover, soil type, acreage available), and time of application (weather, soil trafficability, cropping).

Environmental concerns affecting the method of applying sludge to cropland are: control of surface and groundwater contamination, odor, and aerosol (mist) control. Methods of storage, handling, timing, and rate of application and type of land used, can be managed to minimize these environmental problems.

This section considers application of sludge in the "liquid" form using spray irrigation, overland flow irrigation, tank truck/wagons and immediate soil incorporation. Also, handling sludge cake in the "solid" form using truck spreaders will be discussed. Irrigation equipment will be used primarily by a large city, since the capital costs for equipment capable of pumping, transporting and applying sludge is too great for small cities. Small municipalities will most likely use tank trucks which allow flexibility in selecting application sites and time of application. Immediate soil incorporation can be used with irrigation equipment or tank trucks. Capital costs for dewatering equipment are high so that only larger cities likely will be concerned with applying sludge cake in the "solid" form, with the one exception of small cities that use sand filter/drying beds.

Sprinkler Irrigation: Where sprinkler irrigation is selected, a solid-set system is recommended over a portable pipe system for operating and management reasons. Self-propelled systems, such as center pivot and traveling gun, are also feasible. With the traveling gun system, a large single sprinkler on a carriage is winched across the field, pulling a flexible hose through which the sludge is pumped. Figure 1 shows a travelling gun/flexible hose system. There may be an aerosol drift problem with high pressure sprinkler systems.

Overland Flow: Liquid sludge is discharged at the top of the slope and allowed to flow down. The solids content of the sludge and the slope steepness determine what length of slope is usable. Generally, use of 1 to 2 percent slopes gives good control. This method can be used on wooded as well as grass-covered slopes. A variation of this method, ridge and furrow irrigation, can be used with row crops.

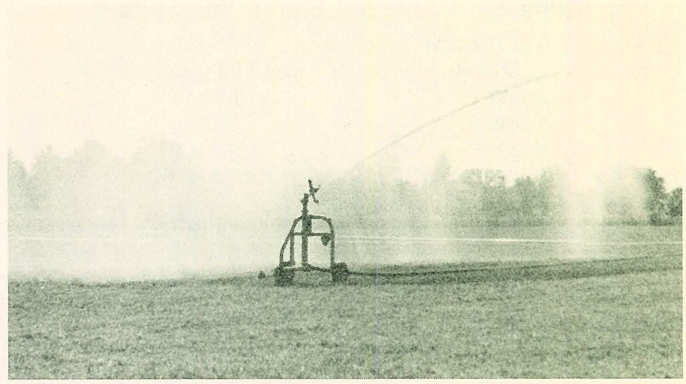

Figure 1. Traveling irrigation system in operation.

Tank Truck: Commercial tank trucks and tank wagons are available. Those with high flotation tires for traversing soft ground may have a restricted hauling range. Regular trucks can be used on grass covered or dry fields. Attachments for tank trucks to allow for field spreading are very simple, involving a quick opening/closing valve and a deflector plate to fan the slurry over a wider area. In most cases, gravity discharge is used, but some commercial tanks can be pressurized or pumped. Figure 2 shows a tank truck with gravity discharge. The tank truck can be elevated to give more uniform discharge and remove solids. Figure 3 shows a truck with a pumped discharge which can be directed to the side. This truck can

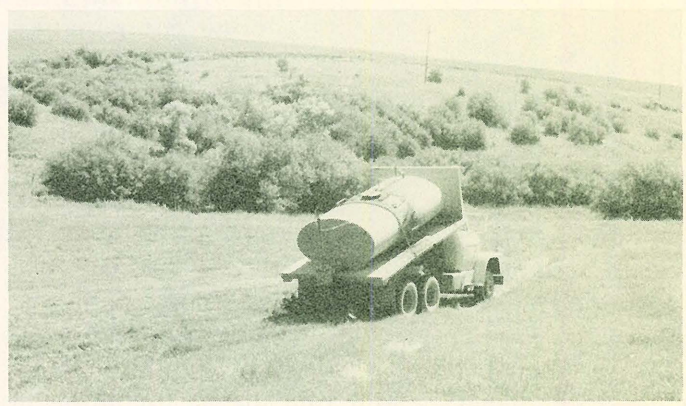

Figure 2. Gravity discharge of sludge with capability of elevating tank.

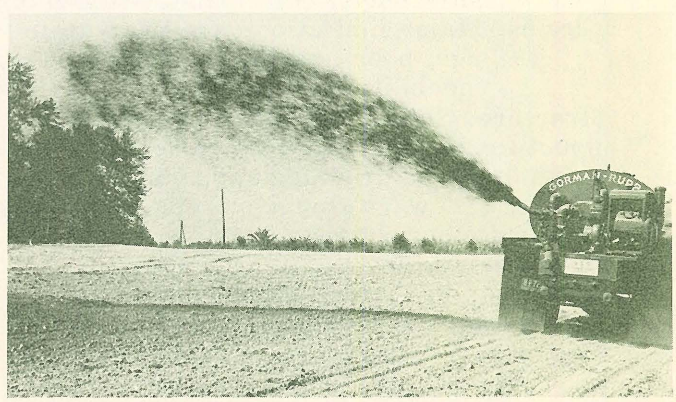

Figure 3. Commercial tank truck with pumped discharge. Photo courtesy of Gorman-Rupp Co., Mansfield, Ohio.

be driven on a road or improved lane during soft ground conditions and spray the waste on the field. Local and state regulations should be checked before discharging sludge from public roads. The use of a pressurized tank or pump discharge should be considered if only one unit is to be used and regular field application is required

Immediate Soil Incorporation: In situations requiring runoff and odor nuisance control, immediate incorporation of sludge into the soil is desirable. This can be done with several types of commercial equipment: chisel injectors on tank wagons, plow furrow cover equipment on tank trucks, surface spreading followed by plowing, and flexible hose attachments to moldboard or disc plows. The first two types are utilized for smaller quantities of sludge. The latter two types are more suitable for large scale operations. Figure 4 shows a tank wagon injecting liquid waste into the soil.

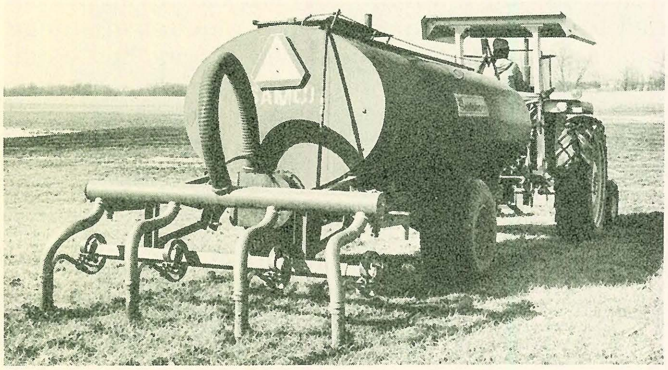

Figure 4. Injecting liquid sludge into soil.

Truck Spreaders: The process of dewatering sludge permits hauling less water to fields. When 5 percent sludge is dewatered to 25 percent, approximately 80 percent of the water is removed. The conventional box spreader has been used for many years to field-spread animal manure. Adaptation of the manure spreader to a truck mounted spreader, as shown in Figure 5, can be used for spreading semi-solid or solid sludges. Truck attachments have been developed for direct incorporation of semi-solid or solid sludge into soil using a moldboard or disc plow.

Figure 5. Truck, box spreader. Photo courtesy of B. J. Manufacturing Co., Dodge City, Kansas.

Crop Management

Sludge contains plant nutrients (See Characteristics of Sludge), and when used by the grower with proper management, it is a valuable supplement to chemical fertilizer. Sludge also can contain varying amounts of metals which can be toxic in the food chain when concentrations are high. Therefore, the quantity of sludge which can be applied safely on soil must take into account the amount of heavy metals applied as well as the nutrient requirements of the crop. When the heavy metal content is high, the sludge application rate will be determined by the amounts of these metals that can be tolerated safely. With "clean" sludges (those low in heavy metals), the application rate will be determined by the nitrogen requirement of the crop, since excess applications of nitrogen can result in contamination of ground and surface waters. Other criteria which should be considered with respect to land application of sludge are pathogens, site characteristics, monitoring, and economic considerations. The last three are covered in other sections.

Pathogens: Some pathogens will reach the soil and vegetation during recycling of sludges. However, due to a relatively rapid mortality of pathogens in the soil, the presence of these organisms should not be a large factor in limiting the applicability of land application of sludge wastes. Root crops or crops eaten raw should not be grown in the year of sludge application.

The application of sewage sludge on dairy farm land is not recommended by the Ohio Department of Health.

Some organisms pathogenic to man may survive the sewage treatment process. These organisms will not survive long once incorporated into the soil. Therefore, when sludges are being handled, normal personal hygiene should be practiced: hats and long sleeve shirts should be worn, don't smoke or eat before washing hands with soap and water, change clothes and shower if possible before returning home. Boots especially should be left outside the house. When a mist is coming from the application, workers should consider the use of face masks.

Excess Trace Elements Including "Heavy Metals": Although sewage sludge contains all nutrient elements essential for the growth of higher plants, it also contains, depending on the source, other elements which might be harmful to crops and to the food chain if applied to soils in excessive amounts. These elements are: Zinc (Zn), Copper (Cu), Nickel (Ni), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Lead (Pb), Boron (B), Molybdenum (Mo), Cobalt (Co), and Selenium (Se).

The trace elements zinc, copper, and nickel are definitely toxic to plants when they occur in soil in significant amounts. Cadmium in high concentration in soil is toxic to plants, but normally cadmium contents of most sludges are not high enough to cause plant injury. Chromium present in sludge applied to soil is converted to a form that is not taken up by or harmful to plants. Lead can be toxic to plants in acid soils which are also low in phosphate. However, lead in the sludge appears to be non-toxic since the large amount of phosphate in sludge ties up the lead and prevents injury to plants. Boron at the levels present in sludge is not harmful to plants, except perhaps in soils normally high in boron. The concentrations of molybdenum, selenium, and cobalt in domestic sludges are so low that in order to reach maximum concentrations in the normal range of natural soils, the application of unrealistically high quantities of sludge would be required.

Trace elements found in sewage sludge, with the exception of cadmium, copper, and zinc, constitute no hazard to the food chain through plant accumulation. However, surface contamination of vegetation by recently applied sludge containing trace elements and subsequent direct ingestion of metals will be a special hazard to grazing animals. Cobalt, nickel and boron at levels that markedly injure plants present no threat in the food chain. Although mercury from the sludge will increase soil mercury levels, the increase in plants will be very small, thus constituting little hazard. Excess zinc is toxic to animals if the diet contains between 500 to 1,000 ppm (parts per million) zinc. Since plant yields are usually significantly reduced at zinc levels less than 500 ppm, the food chain, seemingly, is not jeopardized. Plants exposed to excessive levels of copper will be injured before they can accumulate enough copper to be toxic to most animals. However, sheep are very sensitive to copper. Toxicity results when sheep diets contain 12-15 ppm copper. The potential hazard of cadmium in the food chain is of major concern. Application of sewage sludge containing cadmium increases soil cadmium which in turn can lead to increased food chain cadmium. The suggested acceptable level of cadmium in sewage sludge for land application is less than 1.5 percent of the zinc content of the sludge.

Factors affecting the accumulation of sludge-borne heavy metals by crops are: pH, cation exchange capacity, organic matter, phosphorus, and crop species. In general, the availability of heavy metals in the soil decreases as the soil pH is increased. There is little uptake of heavy metals by plants when soil pH is neutral. Soils with a higher cation exchange capacity have greater retaining power for heavy metals; this, in turn, reduces the amount of heavy metals available to plants. Soil organic matter plays an important role in retaining heavy metals through its high cation exchange capacity and chelating ability. Phosphates reduce the stunting injury to plants from high levels of copper, zinc, and nickel. Plant species and varieties vary in their abilities to accumulate heavy metals. Based on current knowledge of relative crop tolerances to heavy metals, some vegetable crops, e.g., beets, kale, mustard, turnips, and tomatoes, are reported to be very sensitive while others such as beans, cabbage, and collards are considered to be sensitive. Field crops such as corn, soybeans, and small grains are moderately tolerant and most grasses (e.g., fescue, lovegrass, bermudagrass, and perennial ryegrass) are classified as tolerant. The concentrations of heavy metals in the vegetative tissues of plants are much higher than in fruits and seeds.

Various guidelines have been proposed for limiting the rate of sludge additions to soil on the basis of sludge heavy metal content. However, none are totally acceptable at present. One approach, which is presently considered the most useful guide, bases application rates of five important heavy metals on the maximum which can ever be applied to soil (Table 5). The total amount of sludge that can be applied to land will be reached when the allowable level of any one metal is exceeded. The allowable metal additions are higher for soil with greater cation exchange capacity (CEC) and CEC's for a given soil can be approximated from soil texture (Table 4).

Table 5. The Maximum Amounts of Heavy Metals That Can Ever be Applied to Land

Metal	Soil Cation Exchange Capacity (meg/100g soil) 0-5	5-15	more than 15
		Maximum metal addition, pounds/acre	
Zinc	250	500	1000
Copper	125	250	500
Nickel	50	100	200
Cadmium	5	10	20
Lead	500	1000	2000

Sludges having cadmium contents greater than 25 ppm (dry weight) should not be applied to farm land if the cadmium content is greater than 1.5% of the zinc content. It is also recommended that the annual rate of cadmium addition should not exceed 2 pounds/acre. These metal additions apply only to soils that are adjusted to pH 6.5 or greater when sludge is applied, and are to be managed at pH 6.2 or greater thereafter.

Sample Calculation:

1. Assume your sludge contains 2000 ppm Zn, 1000 ppm Cu, 100 ppm Ni, 15 ppm Cd and 500 ppm Pb.
2. Assume your soil CEC is 9.0 meq/100g soil.
3. First calculate maximum sludge addition assuming cadmium will be limiting:

15 ppm Cd x 0.002 x R tons/acre sludge = 10 pounds/acre Cd (from Table 5) R = 333 tons/acre

0.002 = constant; R = maximum tons/acre sludge allowed

4. Now calculate the amounts of other metals supplied in 333 tons/acre sludge:

e.g. 2000 ppm Zn x 0.002 x 333 tons/acre sludge = 1332 pounds/acre Zn

	pounds/acre	Allowable metal loading pounds/acre (from Table 5)
Zn	1332	500
Cu	666	250
Ni	67	100
Cd	10	10
Pb	333	1000

Comparing these with Table 5 indicates that both Zn and Cu will be in excess of allowable levels at this rate.

5. Recalculate loading or application rate using either Cu or Zn as the limiting metal by repeating steps 1-4.

2000 ppm Zn x 0.002 x R tons/acre sludge = 500 pounds/acre Zn

R = 125 tons/acre

6. Following the recommendation of restricting annual cadmium to 2 pounds/acre, the annual sludge application rate would be:

15 ppm Cd x 0.002 x R tons/acre sludge = 2 pounds/acre cadmium

R = 67 tons/acre sludge

This means that the total amount of sludge that can ever be applied, according to this procedure, is 125 tons/acre, and the amount applied in any one year should not exceed 67 tons/acre.

These values indicate maximum application rates to prevent heavy metal toxicity. However, it is also important to apply only enough sludge to provide for the nitrogen needs of the crop. This is based on the nitrogen requirement of the crop and the available nitrogen in the sludge and is discussed in the next section. For forest soils that will not be maintained above a pH of 6.2, the amounts of sludge that can ever be applied should be one-half of the amounts computed from Table 5.

When sewage sludge is to be applied on pastures, concentrations of lead and cadmium in the sludge must be below 1,000 and 22 ppm, respectively, and the cadmium content of the sludge should not exceed 1.5 percent of the zinc. Grazing animals should not be permitted on pastures while crops are physically contaminated by sludge. Thorough removal of sludge from vegetation by rain is required in order to reduce the risk of direct ingestion of the sludge by grazing animals.

Nutrient Requirements: On the average, a ton of dry sludge contains approximately 65, 45, and 5 pounds of nitrogen, phosphorus, and potasium respectively. Application of digested sewage sludge at the rate of 5 tons (dry basis) per acre would furnish about 325 pounds of total nitrogen, 225 pounds of phosphorus, and 25 pounds of potassium. Only about 30 percent of the total mitrogen would be available to crops immediately, and therefore the "crop-available nitrogen" from five tons per acre application of digested sewage sludge would be about 100 pounds of nitrogen per acre. About 5 to 6 percent of remaining nitrogen mineralizes each year. The phosphorus in the digested sludge is readily available for plant uptake. Since digested sludge is not a good source of potassium for crop production, supplemental potassium fertilizer would be required for low K soils. In order to establish a sludge application rate, the following data are required: 1) total and inorganic nitrogen content of sewage sludge; 2) nitrogen, phosphorus, and potassium needs of crop to be grown; and 3) a soil test for available phosphorus and potassium. Although ammonia compounds in the sludge adversely affect the germination of some seeds, a normal germination can be attained if seeding is done at least 1 to 2 weeks after the sludge application.

Also noted should be the loss of ammonia nitrogen if sludge is not incorporated into the soil soon after application.

Since sludge is not a balanced fertilizer, applications over time may result in an imbalance of nutrients. Soil and plant analyses must be used to monitor the levels of available nutrients in the soil (See Testing Section) and supplemental fertilizer should be applied to balance the nutrient supply required by the crop.

Sludge on Crops: Sewage sludge, because of its nature, should not be applied to certain crops such as root crops and leafy vegetables. Sludge should not be applied to pasture crops unless animals are removed from the pasture until the sludge has been washed off the leaves. It should be noted again that there is a greater risk of contamination with foliage crops, including vegetables, forages, and silage, than with grain and fruit crops because contaminants do not accumulate in fruit and grain to the same extent as in leaves.

When sludge is applied on forest crops the degree of nitrogen renovation is an additional environmental concern. If nitrification occurs (low pH (<5.0) in many forest sites may limit nitrification) nitrogen leaching to groundwater or surface water supplies in undisturbed forest soil is a major environmental hazard. Undisturbed forest soils contain large pores that transport water rapidly vertically and laterally. These pores, earthworm and insect tunnels, small mammal burrows, and old root channels may extend downward for several feet, and laterally for tens of feet. In sandy soils, root channels fill up with sand but in finer textured soils, the channels persist like drain tile. Clay skins and root bark prevent water movement from the pores into adjacent soil. Problems associated with vertical and lateral flow will be particularly serious where fractured bedrock or permeable sand or gravels are close to the surface. Pollution of streams by lateral flow could be interrupted by thoroughly disturbing a strip of soil between the sludge application area and the watercourse.

Application of large amounts of liquid sewage sludge on forest sites with steep slopes (>6%) which lead into streams or open drainage systems presents the potential for surface water pollution because of downslope flow of the sludge. Accumulated litter may in most instances be beneficial in retaining the sludge against excessive downslope flow and alleviate the problem. Yet excessive slopes on forested sites must be treated with a great deal of caution since sludge incorporation is usually impossible.

Dried sludge can be used on lawns and ornamental species as long as direct human contact with the material is avoided. Heavy metal and nitrogen limitations also apply to these crops, and it should be noted that some ornamental crops are probably sensitive to heavy metals.

Time of Application: It is best to apply sludge when it can most efficiently be utilized by the crop and, if possible, sludge should be incorporated into the soil to reduce odors and runoff problems. Sludge should not be applied on snow-covered, frozen, sloping land unless there is adequate plant cover or residue to retard runoff. It should not be applied to poorly-drained soil when the water table is near the surface. In general, it is best to apply and incorporate sludge several weeks before planting. Sludge can be applied to established forage stands at most times of the year as long as adequate time is given for the sludge to wash into the soil before the forage is cut or animals are allowed to graze. Trees are perennial crops and must survive cold winters in many areas of the country. Application of sewage sludge in late summer or early fall could prevent development of cold hardiness by stimulating a new flush of rapid twig growth. Therefore, sludge should not be applied to forest land in late summer or early fall. The optimum time for application will be in spring and early summer up to around July 15. Late fall or winter applications may be useful if nitrogen leaching and surface runoff are not problems.

Economic Considerations

Substituting Sludge for Commercial Fertilizer: Valuing sludge as a substitute for commercial fertilizer is complicated by its variable chemical composition and by fluctuating fertilizer prices.

Table 6 presents three price levels for fertilizer to be used in arriving at the nutrient value of sludge.

Table 6. Assumed Prices for Fertilizer Nutrients

Nutrient	Price Range (Dollars/Pound) High	Medium	Low
N (Nitrogen)	.30	.20	.10
P_2O_5 (Phosphate)	.25	.20	.15
K_2O (Potash)	.12	.10	.08

Table 7 demonstrates the range in the fertilizer replacement value of sludge which Ohio municipalities might provide using the price levels shown in Table 6.

Table 7. Value of Nutrients in One Ton of Dry Sewage Sludge Under Nine Alternative Assumptions for Nutrient Content and Commercial Fertilizer Price*

Nutrient Content	Value of Nutrients in Sludge** High	Medium	Low
Low (N=2.0%, P_2O_5=1.1%, K_2O=0.12%)	$ 9.80	$ 7.30	$ 4.80
Medium (N=3.3%, P_2O_5=5.3%, K_2O=0.4%)	34.00	26.40	18.70
High (N=5.0%, P_2O_5=9.2%, K_2O=2.4%)	61.70	48.20	34.70

*It is assumed that one-third of the total N would be immediately available to crops while all of P_2O_5 and K_2O would be available.
**Based on three different levels of fertilizer prices.

Table 7 demonstrates that the value of sludge varies tremendously as a fertilizer replacement. The value may vary from $10.40 per ton to approximately $63.00 per ton. Thus, landowners will need to carefully determine the current sludge content and nutrient value in making a decision relative to having sludge applied to their land.

Landspreading Costs

The costs of landspreading depend on the type of application equipment used, the distance which the sludge is hauled, the volume of sludge hauled, and the extent of testing and monitoring. A recent survey of landspreading communities indicates that costs average about $31 per dry ton to spread treated sludge under currently used practices. Economies of size are present in sludge spreading. The total cost for a treatment plant with a 2 million gallon per day flow is $70 per dry ton while the costs for a plant of 20 million gallons per day flow is $24 per dry ton.

Landspreading costs are favorable when compared to other sludge disposal alternatives. Landfilling or incineration are the primary disposal alternatives. Generally, both of these alternatives have higher sludge disposal costs than landspreading.

Testing

Routine tests should be made on sludge before the material is used. Several of these determinations are the same as those used in routine soil analyses. Organic matter, pH, and soluble salts content (electrical conductivity) tests of the sludge should be made. Sludges from different municipalities vary considerably in their moisture content and, therefore, total solids (dry matter) determinations must be made before any recommendations can be given regarding the amount of material to apply.

The nutrient element content of sludge must be measured to help determine if additional fertilizer should be added to balance the amount of nutrients supplied. Types and quantities of metals in sludge vary considerably from one municipality to another, and even at a given facility depending on when the sludge is sampled. Metals would be expected in greatest amounts in sludge from municipalities which service certain kinds of industries. Conversely, these metals will probably be less significant in sludge from primarily residential areas. However, determinations of the metal content should be made regardless of source. All test results should be made available to the grower well in advance of land application to allow enough time to determine application rates.

Standard soil tests should be made prior to sludge application so growers can determine the total amounts of nutrients that will be available from both sludge and soil. Samples for this test should represent no more than 20 acres. These tests consist of pH, cation exchange capacity, lime test index, available phosphorus, exchangeable potassium, calcium and magnesium. Additional tests should be made for available zinc, boron, and possibly molybdenum. Waterways adjacent to the anticipated application area and nearby springs and wells should be tested to determine background levels of nitrate-nitrogen and coliform bacteria.

Monitoring Schedule After Application

The soil tests mentioned above should be made each year prior to fertilizer applications. Some constituents of sludge will remain in the soil for many years while others will disappear rather rapidly. If any nutrient imbalance in the crop is suspected, plant analyses should be used to help diagnose potential nutritional problems, either toxicities or deficiencies. Heavy metal analyses of consumable plant parts from sludge-amended soils is desirable, especially when amounts applied approach or exceed recommendations given in this publication. Water sources originating near the sludge application area and eventually discharging into larger streams should be periodically sampled and tested for the presence of trace elements and nitrates. Local health departments will test private water supplies upon request.

It is important to point out that in addition to heavy metals, sewage sludge may contain some persistent compounds which may be harmful to crops. Since these compounds cannot be identified easily, simple seed germination tests in both uncontaminated soil and soil mixed with sewage sludge are desirable.

Procedure for Collecting, Handling, and Submitting Sludge for Analysis

When submitting a sample for analysis, the name of the municipal sewage treatment plant should be provided so that sludge from different localities can be characterized, to help develop sound recommendations for the grower who uses sludge as a fertilizer. Tests of sludge samples can be conducted by several laboratories located around the country. County Extension offices are being provided the addresses of known facilities. Furthermore, some of the larger municipalities either have or are obtaining the capability to analyze sludge.

Sludge should be collected in water-tight, airtight plastic containers of approximately one pint size, depending on the estimated water content.

The table below indicates the sample size to be collected relative to the estimated water content.

Water Content	Solids	Volume to Collect	or	Weight to Collect
98%	2%	1 gallon		8 lbs.
95	5	1 1/2 quarts		3.2 lbs.
90	10	1 1/2 pints		1.6 lbs.
80	20	1 pint		0.8 lbs.
70	30	1/2 pint		0.5 lbs.

Social Concerns

The concept of land application of sludge for crop production has been used for centuries in the Asiatic and European countries. They consider sludge as a valuable natural resource which can replace fertilizers and increase crop yields.

A key consideration in determining the practicability of land application of sludge is whether landowners, farmers and other persons in the community do in fact see an advantage to receiving this material and view the material as not being a problem from the standpoint of either economic, health or nuisance considerations. Past experiences have clearly demonstrated the need for landowners and other affected citizens to be involved in the decision-making process at the earliest possible time. It is essential to determine what economic benefits are expected to accrue to the person who received the material as well as to demonstrate what long and short term effects the application of sludge will have upon the land. Landowners are interested in knowing the characteristics of the material under consideration, i.e., the extent of heavy metals, the nature of the product such as whether it is to be five percent solids or thirty percent solids, and how much moisture this means would be applied to the land. They also must be given information about alternative methods available for application, crop management practices, and monitoring safeguards that can be taken to ensure that protection is provided against any detrimental effects.

The following considerations with regard to an educational program are recommended:

Educational materials must be developed which:

—clearly and concisely state current status of sludge disposal in the community involved and indicate the likely future possible sequence of events.

—depict what information is of a specific nature and which can be generalized

—clearly outline the practical alternatives involving land application of sludge

—supply a means to permit local landowners and citizens to evaluate these alternatives **before** final recommendations are made

This will require a simplified analysis of the pros and cons of each alternative. This information should include not only the technical aspects but the social, economic and political aspects as well.

Those involved in an educational program should not try to "sell" any one proposed alternative. (Every effort must be made to provide local citizens opportunities to make choices). Any educational effort should let it be known early that its main function is to disseminate information and provide an objective forum for discussion of the various alternatives in dealing with the whole question of sludge disposal.

An opportunity should be provided for interested persons to visit sites where sludge has been applied to the land. In addition, where possible, it would be desirable to establish demonstrations at several farms located in the area under consideration.

An educational or information program should accompany the establishment of such demonstrations. A program should be one where:

—the problem is clearly identified

—factual information regarding alternative solutions is presented

—a forum is provided for input by all interested

—it is recognized that in the final analysis the decision of which alternative is implemented is made by the people

Effort must be made to make certain that all possible factual information relating to the demonstration is presented.

Relationship Among Agencies

The authority of the Ohio Environmental Protection Agency to regulate land application of sewage sludge is derived from both state and federal laws. Sections 6111.44 and 6111.46 of the Ohio Revised Code require that plans for all sewage treatment systems be submitted to OEPA for approval. Approval will be based on whether or not the proposed system will pollute the state's waters, present a hazard to the public's health, or cause a public nuisance. The National Environmental Policy Act (NEPA) of the U.S. Congress also requires that an environmental assessment be prepared for any proposal which would receive federal funds. In practice, this means that plans and, if appropriate, an environmental assessment should be submitted to the OEPA. The OEPA engineers and planners would then verify that the proposal is based on sound engineering judgment and that it would not cause significant water pollution or present a threat to the public's health. If federal funds are involved, OEPA would also verify the cost effectiveness of the proposal and consider the overall environmental impact of the proposal.

It is important for landowners to understand that an approved plan for sludge application does not remove their responsibility for water pollution or health hazards that result from the application of this sludge on their land. Plan approval means that in the judgment of OEPA the proposed system should function satisfactorily. However, it is possible that unforeseen problems might arise. In such situations the OEPA would give the landowner a reasonable period of time to rectify the problem. Of course, the landowner should also reserve the option to discontinue sludge application on farmland in the event of such unforeseen problems.

The local health department would become involved only if a nuisance or health hazard situation were to exist. It is recommended that landowners contact the local health department for guidance and support prior to applying sludge to their land.

Revised 5/76—2M

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Roy M. Kottman, director of the Cooperative Extension Service, The Ohio State University.